GRAVITY CAN BEND LIGHT

Unit 8 , Dr. John P. Cise, Professor of Physics, Austin Com. College, Austin Texas USA, jpcise@austincc.edu July 31, 2017 by Dennis Overbye, Dedicated to my Phys. Profs. Dr. Poldusky

The Eclipse That Revealed the Universe

INTRODUCTION 1: What is General Relativity? Einstein's theory proposes that gravity is not an actual force, but is instead a geometric distortion of spacetime not predicted by ordinary Newtonian physics. The more mass you have to produce the gravity in a body, the more distortion you get. **This distortion changes the trajectories of objects moving through space, and even the paths of light rays, as they passes close-by the massive body.** Even so, this effect is very feeble for an object as massive as our own sun, so it takes enormous care to even detect that it is occurring! **INTRO 2: (SEE EQUATION OF LIGHT BENDING BELOW)** Here is a rough explanation of the origin of those constants. The 2 for Newtonian gravity is from integrat- ing angular factors like cosine and sine that determine the position of the photon as it moves and past the sun. The most interesting constant is the 4 for general relativity, which is twice the Newtonian value because light moves at the speed of light. The extra bending is a consequence of Einstein's theory of special relativity putting space and time on the same level. The theory of general relativity then formulates gravity in terms of the curvature of spacetime. Newton's theory is the limit of general relativity that considers only time curvature; general relativity itself also calculates the space curvature. Since most objects move much slower than the speed of light, meaning that they travel curvature. The Newtonian analysis is fine for those much farther in time than in space, they feel mostly the time objects. Since light moves at the speed of light, it sees equal amounts of space and time curvature, so it bends twice as far as the Newtonian theory would predict.

A view of the 1919 solar eclipse, observed in Sobral, Brazil. Arthur Eddington set out to verify Einstein's prediction that gravity could affect the course of starlight. CreditA.Eddington

In 1919, British astronomers photographed a solar eclipse and proved that light bends around our sun — affirming Einstein's theory of general relativity.

$\alpha = [2 GM]/c^2R$

Newton's estimate of light deflection by sun in radians.

$\alpha = [4 GM]/c^2R$

Einstein's estimate of light deflection by sun in radians.

So this is what it is like to play cosmic pinball. The worlds move, and sometimes they line up. Then you find yourself staring up the tube of blackness that is the moon's shadow, a sudden hole in the sky during a total solar eclipse. Few eclipses have had more impact on modern history than the one that occurred on May 29, 1919, more than six minutes of darkness sweeping across South America and across the Atlantic to Africa. It was during that eclipse that the **British astronomer Arthur Eddington ascertained that the light rays from distant stars had been wrenched off their paths by the gravitational field of the sun.** That affirmed the prediction of Einstein's theory of general relativity, ascribing gravity to a warp in the geometry of space-time, that gravity could bend light beams. Eddington's report made Einstein one of the first celebrities of the new 20th century and ushered in a new dynamic universe, a world in which space and time could jiggle, grow, warp, shrink, rip, collapse into black holes and even disappear.

QUESTIONS: (a) Find radian deflection of light by sun from Newton? ,(b) Find radian deflection of light by sun from Einstein?,(c)Convert (a) & (b) to degrees?,(d)Convert degree deflection in each case to arcseconds? (e)Which method fits experimental verification listed in table below? HINTS: 360 degrees/2π,3600 arcseconds/degree, G = gravitational con. = 6.67×10^{-11} N $m^2/kg.^2$, $M_{SUN} = 2 \times 10^{30}$ kg., c = 3×10^8 m./s., $R_{SUN} = 7 \times 10^8$ m., ANSWERS:(a) $\alpha_{NEWTON} = 0.4235 \times 10^{-5}$ radians , (b) $\alpha_{EINSTEIN} = .847 \times 10^{-5}$ radians, (c) $\alpha_{NEWTON} = 24.275 \times 10^{-5}$ degrees, $\alpha_{EINSTEIN} = 48.55 \times 10^{-5}$ degrees, (d) α_{NEWTON} = 0.875 arcseconds, $\alpha_{EINSTEIN}$ = 1.75 arcseconds, (e) Einstein's methodology fits experimental verification starting in 1919 seen below.

The British astronomer Arthur Eddington, who discovered that light rays from distant stars would bend from the gravitational field of the sun, an affirmation of one of the more dramatic predictions of Einstein's theory of general relativity.

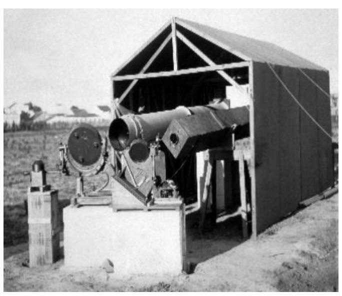
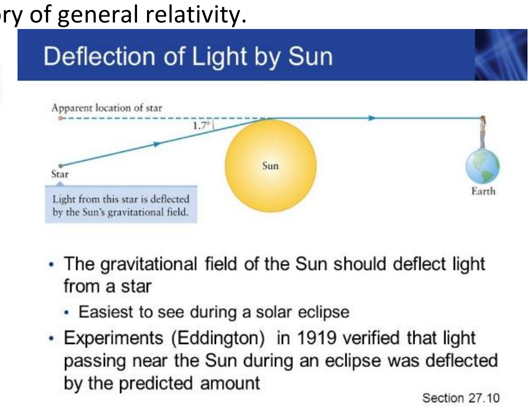


Table 1: **Eclipse Measurements of the Gravitational Deflection of Starlight (1919 – 1973):** Column (1) gives the number of the observation in the table. Column (2) and (3) gives the date and location of execution of the eclipse observations. Column (4) gives the actual measurements made, while column (5) and (6) gives the γ-factor. Column (7) gives the deviation of the measurement from Einstein's expected 1.75″ Solar deflection. Lastly, column (8) gives the number of stars observed for the particular observational run.

	Date	Location	Measurement δ_D (arcsec)	γ-Factor	Deviation (%)	Number of Stars
(1)	May 29, 1919.	Sorbal	1.98 ± 0.16^a	1.14 ± 0.07	$+13.10 \pm 0.80$	7
(2)		Principe	1.61 ± 0.40^a	0.90 ± 0.20	-8.00 ± 2.00	5
(3)	Sept. 21, 1922.	Australia	1.77 ± 0.40^b	1.00 ± 0.20	$+1.10 \pm 0.30$	11 – 14
(4)			1.80 ± 0.40^c	1.00 ± 0.20	$+2.90 \pm 0.60$	18
(5)			1.72 ± 0.15^d	1.00 ± 0.10	-1.70 ± 0.10	62 – 85
(6)			1.82 ± 0.20^d	1.10 ± 0.10	$+4.00 \pm 0.40$	145
(7)	May 9, 1929.	Sumatra	2.24 ± 0.10^e	1.29 ± 0.06	$+28.00 \pm 1.00$	17 – 18
(8)	June 19, 1936.	USSR	2.73 ± 0.31^f	1.60 ± 0.20	$+56.00 \pm 6.00$	16 – 29
(9)		Japan	1.70 ± 0.40^g	1.00 ± 0.20	-2.90 ± 0.70	4 – 7
(10)	May 20, 1947.	Brazil	2.01 ± 0.27^h	1.20 ± 0.20	$+15.00 \pm 2.00$	51
(11)	Feb. 25, 1952.	Sudan	1.71 ± 0.10^i	0.98 ± 0.06	-2.30 ± 0.10	9 – 11
(12)	Oct. 2, 1959.	Sahara	2.17 ± 0.34^j	1.20 ± 0.20	$+24.00 \pm 4.00$	11
(13)	June 30, 1973.	Mauritania	1.66 ± 0.19^k	1.00 ± 0.10	$+5.10 \pm 0.60$	39
	Weighted Mean	⟼	**1.92 ± 0.05**	**1.10 ± 0.50**	**$\langle S \rangle = 13.00 \pm 2.00$**	**395 – 440**

References: [a]Dyson et al. (1920); [b]Dodwell & Davidson (1924); [c]Chant & Young (1924); [d]Campbell & Trumpler (1923); [e]Freundlich et al. (1929, 1931, 1933); [f]Mikhailov (1940, 1949); [g]Matukuma (1941); [h]*van* Biesbroeck (1949); [i]*van* Biesbroeck (1953); [j]Schmeidler (1963); [k]Jones (1976)



Instruments used during the solar eclipse expedition in Sobral, Brazil

According to Einstein's final version of the theory, completed in 1915, as their light rays curved around the sun during an eclipse, **stars just grazing the sun should appear deflected from their normal positions by an angle of about 1.75 second of arc,** about a thousandth of the width of a full moon. According to **old-fashioned Newtonian gravity, starlight would be deflected by only half that amount, 0.86 second, as it passed the sun during an eclipse.**